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R. C. WINGER

A PORTABLE APPARATUS FOR MEASURING MAGNETIC FIELDS

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A PORTABLE APPARATUS FOR MEASURING MAGNETIC FIELDS

BY

REINHARD CONRAD WINGER

A Thesis Submitted for the Degree of
BACHELOR OF PHILOSOPHY

UNIVERSITY OF WISCONSIN

1913

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A Portable Apparatus for Measuring Magnetic Fields.

The problem assigned for this thesis was to design and construct a portable apparatus which is capable of measuring accurately, magnetic fields varying from very weak fields to fields of great intensity.

In constructing a portable apparatus of this nature a number of essential factors must be considered. In the first place it must be compact so as to take up as little space as possible, and of such weight as to permit it being carried about easily. The instrument must be fairly sensitive in order to permit an accurate determination of very weak fields as well as of very strong ones. Lastly, it must be constructed with a view of reducing the effects of external conditions to a minimum. The above mentioned factors have beenkept in mind in working out the details of the problem assigned for this thesis.

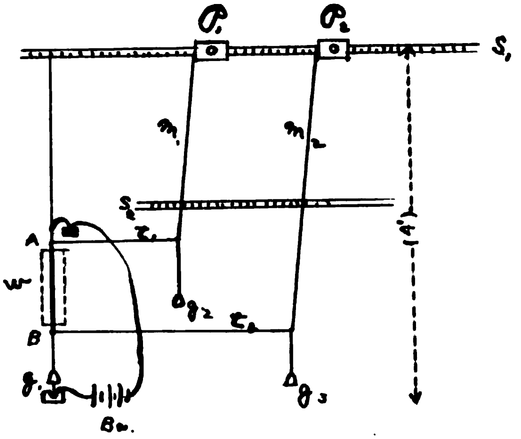
Before going into details regarding the construction and use of this apparatus it may be well to briefly review the various methods in use for determining the strength of magnetic fields. There are four general methods in use,viz.

(1) The traction method.
(2) Comparison by use of earth inductor.
(3) The ballistic method.
(4) The fluxmeter.

The traction method:

This method was devised by Lord Kelvin and has a wide range of use in magnetic measurements.

The following diagram shows the method as originally devised.



AB = wire between pole pieces.
G = known weights.
W = pole pieces of magnet.
Ba= battery.

To operate, move P_1 and P_2 so that t_1 and t_2 are slack. Mark position of AB on pole of magnet and send a measured current through AB in such a direction that AB is forced to the left. Now P_1 and P_2 are moved so as to bring AB back to its original position. Knowing the weight of G, the displacement on the scales S_1 and S_2, the vertical distance between scales, and other measured conditions, it is possible to find the value of the field by substituting the values in the following equation:

$$I = \frac{WG(d_1 + d_2)}{L\ C\ l}$$

where

I = average intensity of field.
W = the mass of each pendulum bob in grams.
g = the attraction of gravity.
L = length of opposing pole faces.
$d_1 + d_2$ = sum of the differences over which wires M and M have moved on S_1 and S_2.
l = perpendicular distances between point of suspension of wires to bottom of lower scale.

In using this method the operator will find the following difficulties:

1. The apparatus is not a convenient one to carry about as it occupies too much space.
2. In order to use this method it is necessary to have a measured current. This makes it necessary to carry batteries and to depend on ammeters at all times.

(3) The method does not seem to adapt itself to the measuring of vertical fields, or to fields that lie between curved pole pieces.

(4) As the apparatus is shown above, it can be used only to determine the average intensity of the field.

The apparatus has been modified in a number of ways but several of the difficulties mentioned still exist. The instrument uses a measured current at all times and this fact makes it inconvenient to use it as a portable instrument.

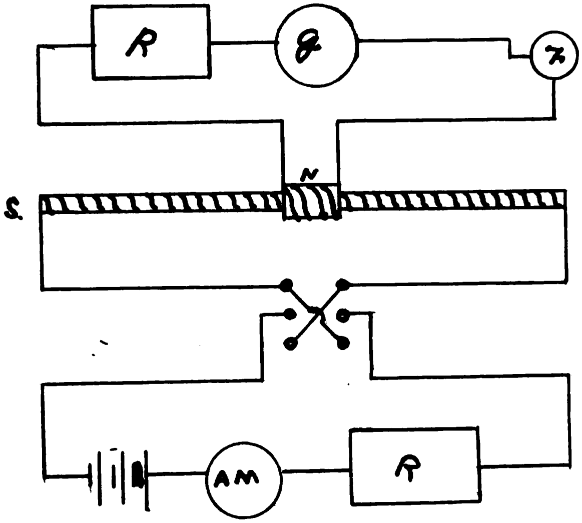
Comparison by Use of Earth Inductor:

This method consists in comparing the throw of a ballistic galvanometer due to an exploring coil, placed in the field to be measured and suddenly withdrawn, with the deflection of the galvanometer due to the swinging of the coil of an earth inductor through a suitable angle. In order to get the value of the quantity of electricity induced by the inductor it is necessary to know the horizontal component of the earth's magnetic field. This force varies according to the time, and the place where determined, and therefore is not sufficiently constant to be used for the purpose of standardizing a galvanometer. The apparatus has not been made compact so as to be readily carried about.

The Ballistic Method:

The essential principle of the ballistic method consists in comparing the deflection of a ballistic galvanometer caused by an exploring coil in the field, with the deflection caused by the induced

current in the secondary coil of a solenoid when a measured current is sent through the primary. The following is a diagram of this method.



R= resistance.
F= exploring coil.
G= galvanometer.
S= standard solenoid.
N= secondary of solenoid.
AM= ammeter.
Ba= battery.

This method is perhaps the most accurate of the three methods mentioned because it is less likely to be affected by outside conditions and is perhaps easier of manipulation than the other methods. There are several factors that prevent its use generally. In the first place it is too cumbersome to be carried from place to place easily and, secondly, it always requires a measured current and would be open to the same criticism that all apparatus using currents are subject to.

* * *

The Fluxmeter:

The fluxmeter is simply a ballistic galvanometer calibrated with an exploring coil so as to read the deflection directly in gausses. The instrument which was tested was only intended for small fields. Should it be desired to measure more intense fields, a resistance would have to be placed in the circuit and the

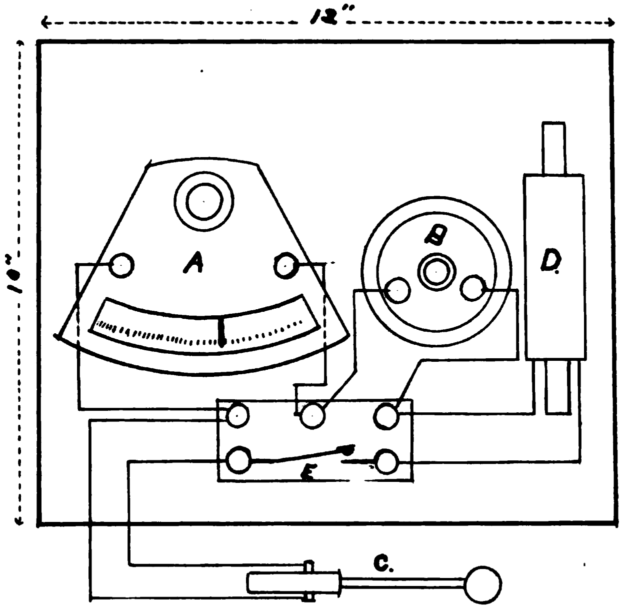
whole instrument calibrated again. There is no way of telling the degree of accuracy of the instrument except by taking it and testing it out by means of a standard solenoid.

* * *

Description of the apparatus constructed and used in this thesis.

The primary purpose, as already stated, was to construct a portable apparatus which could be used under varied conditions. An attempt has been made to avoid the difficulties of the other methods both from the standpoint of portability and of use. To avoid the necessity of using a measured current, a standard has been selected, the Hibbert's standard magnet, which stays constant to within two- third of one percent under all ordinary conditions. Then a ballistic galvanometer with a pointer for reading deflections is used since it offers the easiest method for determining the amount of deflection readily. In addition a number of exploring coils have been constructed. The apparatus then, in brief, consists of a ballistic galvanometer, a Hibbert's standard magnet, and an exploring coil which is to be introduced into the field to be tested. All these pieces are joined in series in order to maintain a constant resistance in the circuit and the whole is mounted on a case so as to be easily carried from place to place.

Diagram of the apparatus as mounted.



A= Ballistic Galvanometer.
B= Hibbert's magnet.
C= Exploring coil.
D= Resistance and magnet for zero adjustment.
E= switch.

The galvanometer:

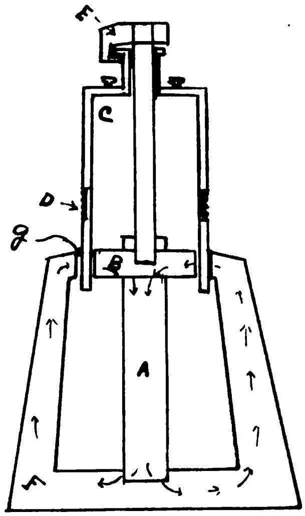
The galvanometer used is a " Mirror and Pointer Moving Coil Galvanometer, Ballistic Type". The instrument was manufactured by W.G.Pye and Co., Cambridge, England, and the following data was furnished with the instrument.

Deflection per micro ampere at one meter radius	90mm
Deflection per micro ampere with pointer	5 1/4 div.
Periodic time in seconds	9 seconds
Resistance of the coil in ohms	30.2 at 16 degrees.
The mirror	plane.

For ordinary purposes the throw of the galvanometer as indicated by the pointer is sufficiently accurate but should a more accurate result be desired, the swing of the mirror can be determined by means of a telescope and a scale. The galvanometer is mounted on the case in such a manner that it cannot be lifted off but still it is free enough so that it can be easily leveled. A slide is provided at the side of the galvanometer so as to lock the system when the apparatus is carried from place to place.

Hibbert's Magnetic Standard:

The standard consists of a strong permanent magnet, the top of which is a circular pole piece and the bottom of which is an iron cup. The figure below gives a cross section of the standard, the various parts being as follows:



A = Permanent magnet.
B = Circular disc at the top of the magnet.
C = Brass cylinder.
D = Coil of insulated wire wound around cylinder.
E = Catch to hold cylinder above field.
F = Cup of soft steel through which lines of magnetic force pass.
G = Narrow gap across which the lines of magnetic force pass.

A study of the above diagram shows that the lines of magnetic force pass across a very narrow annular gap. This feature beside increasing the number of lines available also insures the constancy of the instrument. Hibbert has tested the constancy of the magnet under varying conditions extending over an indefinite time and he found that the largest variation never exceeded two-third of one percent.

The electric impulse is generated in the circuit by dropping the brass cylinder on which is wound a number of turns of insulated wire, through the gap. This impulse or current (Q) is a function of the number of turns (t) in the coil, the number of lines cut(N), and the resistance (R) in the circuit.

$$\text{or } Q = \frac{Nt}{R} \qquad (1)$$

Hibbert's Standard Magnet is used in place of a solenoid with a measured current, and it is more accurate and reliable because its constancy is practically perfect if no violence is used with it. Ordinary handling or overheating is without effect.

The Exploring Coils:

A number of exploring coils have been provided. They ere to be placed in the circuit as shown, and are used by being introduced into the field to be measured and suddenly withdrawn. The area of each coil and the number of turns of insulated wire in each are given. Knowing this, it is possible to determine the strength of a magnetic field by comparing the deflection due to the current induced by the coil with the deflection due to the current induced in the circuit by the Hibbert's standard magnet.

Accessories:

Additional resistance has been placed in the circuit for the purpose of increasing the resistance of the latter sufficiently to prevent the pointer from turning off the scale when the current is induced by the Hibbert's standard magnet. At the same time this resistance coil is used as a zero control for the galvanometer by having a permanent magnet within it. This magnet is free to move back and forth within the coil. By moving this magnet back and forth it is possible to change the position of the pointer and also to bring the pointer

the more rapidly at rest at zero. A switch has been placed in the circuit so as to open and close the circuit as needed. It is often convenient to have the switch open while introducing the exploring coil into the field in order to prevent unnecessary movement of the galvanometer pointer. A drawer has been provided for keeping the coils and such other accessories as are needed.

The Advantages of the Method:

The method described above has one great advantage over other methods in that it can be carried readily from place to place.and used without resorting to measured currents. The method is less affected by outside conditions because the standard is so constructed that it is constant under all ordinary conditions, and the galvanometer is standardized by means of the standard for each experiment. The method, by using exploring coils of suitable sizes, is adapted for measuring fields of any intensity. It would seem from this, that this method is the most practical method to employ whenever accurate results are wanted immediately.

The General Method:

The method used for determining the strength of a magnetic field is one of comparison. It consists in comparing the deflection of the galvanometer due to the Hibbert's standard magnet with the deflection due to an exploring coil that is introduced into the field

to be measured and suddenly turned or withdrawn.

If Q_1 and Q_2 represent the quantity of electricity generated by the Hibbert's standard magnet and the exploring coil respectively, then the following proportion holds, from (1).

$$Q_1 : Q_2 = \frac{N_1 t_1}{R_1} : \frac{N_2 t_2}{R_2} \qquad (2)$$

where N_1 = flux through Hibbert's standard magnet.
N_2 = flux through exploring coil in magnetic field.
t_1 = number of turns on brass cylinder.
t_2 = number of turns on exploring coil.
R_1 and R_2 = resistance of respective circuits.

Since both the Hibbert's standard and the exploring coil are on the same circuit, the resistance R_1 and R_2 above are identical and may be ommitted. Equation (2) then becomes,

$$Q_1 : Q_2 = N_1 t_1 : N_2 t_2 \qquad (3)$$

But Q_1 and Q_2 are proportional to the deflections D_1 and D_2 of the galvanometer. Equation (3) becomes

$$D_1 : D_2 = N_1 t_1 : N_2 t_2 \qquad (4)$$

Solving (4) for the value of N_2 we have

$$N_2 = \frac{N_1 t_1 D_2}{t_2 D_1} \qquad (5)$$

To reduce the field strength to gausses equation (5) is divided by the area of the exploring coil (A). Then equation (5) becomes

$$\frac{N_2}{A} = \frac{N_1 t_1 D_2}{t_2 D_1 A} \qquad (6)$$

Equation (6) is the equation that is used in computing the intensity of a magnetic field with the above method. The equation is one that can be readily solved by means of a slide rule.

Standardizing the Hibbert's Standard Magnet:

In determining the total flux through the narrow gap of the Hibbert's standard magnet, a standard solenoid is used with a measured current and the quantity of electricity induced in the secondary coil of this solenoid is compared with the quantity of electricity induced by the Hibbert's standard magnet. For this purpose both are placed on the same circuit with a ballistic galvanometer. The throw of the galvanometer in each case is proportional to the total quantity of electricity which passes through the circuit. The theory is as follows:

Let

n= number of turns on secondary of solenoid.
Q = quantity of electricity discharged through the galvanometer.
i = instantaneous current in gal. circuit.
ϕ = flux in standard solenoid.
B = induction in standard solenoid.
H = field strength in standard solenoid.
d = deflection of the galvanometer.
K = constant of the galvanometer.

Then

$$dQ = Kd = i.dt. \qquad (1)$$

but

$$i = \frac{e}{R} = \frac{-n}{R10^8}.\frac{d\phi}{dt} \qquad (2)$$

Hence

$$K.d = -\int_0^T \frac{n}{R10^8}.\frac{d\phi}{dt}.dt. \qquad (3)$$

If the current is reversed through the standard solenoid the flux,,in time T, will pass from ϕ to $-\phi$, therefore by changing limits of integration

$$K.d. = -\frac{n}{R.10^8}.\int_{+\phi}^{-\phi} d\phi, \qquad (4)$$

integrating

$$K.d = \frac{2n.\phi.}{R.10^8} \qquad (5)$$

But $\phi = BA = HA$ in a solenoid without a ferromagnetic core.

and $$H = \frac{4\pi NI}{10L} \qquad (6)$$

therefore $$K.d = \frac{8\pi NIAn}{10^8 R\ L} \qquad (7)$$

The total quantity(Q_1) induced in the circuit by the Hibbert's standard magnet is equal to the following:

$$Q_1 = \int_0^T \frac{n_1 d\phi\ dt}{10^8 Rdt} = \frac{n_1}{10^8 R}\int_0^\phi d\phi. \qquad (8)$$

Integrating

$$Q_1 = Kd = \frac{n_1 \phi}{10^8 R} \qquad (9)$$

Now the current in the standard solenoid can be regulated so that the deflection of the galvanometer will be the same whether the current is induced by the secondary of the solenoid or the Hibbert's magnetic standard. Therefore equations (7) and (9) are equal when this condition is brought about.

or $$\frac{8\pi NIAn}{10^8 R\ L} = \frac{n_1 \phi_1}{10^8 R} \qquad (10)$$

Solving for ϕ_1;

$$\phi_1 = \frac{8\pi NIAn}{10\ L\ n_1} \qquad (11)$$

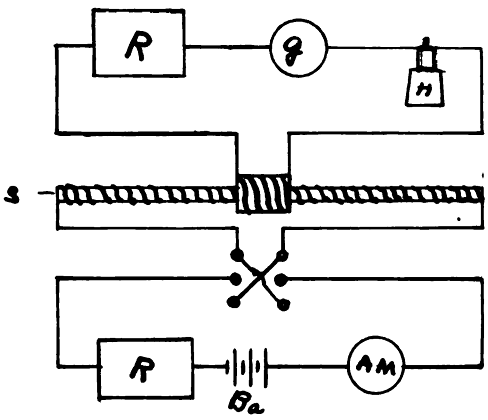
The solution of equation (11) gives the total flux through the narrow annular gap of the Hibbert's standard magnet.

Method of procedure:

The apparatus is set up as shown below and such a measured current is sent through the standard solenoid as will cause the same deflection in the galvanometer, as will the Hibbert's standard magnet.

In performing the experiment the current was reversed through the standard solenoid, as equation (11) was determined with this manipulation in view.

The Experiment was set up as shown in the following diagram.



H= Hibbert's standard magnet.
G= Ballistic Galvanometer.
S= standard solenoid.
Ba= storage battery.
Am= ammeter.
R= resistance.

This experiment was tried several times with different secondary coils on the solenoid with results as follows:

Date Year 1912.	Dec. 26.	Dec.26.	Dec.28.	Dec. 28.
current in amperes	4.45	6.75	6.725	4.425
deflection	9	9	14.55	14.55
No. of turns on secondary solenoid.	600	392	392	600
Def. of gal. with Hibbert's standard.	9	9	14.55	14.55
Distance from telescope to gal.	1 meter	1 meter	1.64 m.	1.64m
temperature.	28.8	28.8	30	30
Total flux ϕ thru Hibbert's standard.	31890	31623	31492	31716

The average of the two results where there are 392 turns onthe secondary is used as average flux.

Average total flux= 31557 lines.

In obtaining the above flux the following additional data was used.

Number of turns on the Hibbert's Magnet = 9.
Diameter of the standard solenoid = 3.176 cm.
$\frac{N}{L}$ or the number of turns per unit length of the solenoid = 5.4.

Application of the Method:

The apparatus was tried out by testing the field strength between the poles of an electro magnet when different measured currents were sent through the magnet. A number of determinations were made.
As these results compared very closely with one another only one of these determinations will be given here.
It was found necessary when using the pointer in reading the deflection to estimate the deflections to one-tenth of one of the smallest divisions on the scale. With a little practice this can be done accurately. In operating the apparatus one must be certain that the pointer is at zero before sending an induced current through the galvanometer. A few precautions as ~~these~~ will add to the accuracy of the results. The strength (H) of the field was determined by substituting the proper values in the following equation. (For the method of deriving the equation see page 11.).

$$H = \frac{N_2}{A} = \frac{N_1 t_1 D_2}{t_2 D_1 A}.$$

Data:

The pole pieces of the electro magnet were 5mm apart.
Average diameter of exploring coil = 1.482 cm.
Number of turns on exploring coil = 10

Current thru electro mag.	Def. due to explor. coil.	Def. due to Hibbert's M.	Field strength of electro mag.
0			
.5	4	39	1688
1.	7.8	39	3293
1.5	12.3	39	5192
2.	16.6	39	7018
2.5	20.5	39	8654
3.	25	39	10553
3.5	29	39	12242
4.	32.7	39	13802
4.5	37	39	15020
5.	39	39	16464
5.5	40.8	39	17224
6.	42	39	17730
6.5	43	39	18154
7.	43.8	39	18490
7.5	44.4	39	18743
8.	45	39	18997
9.	46	39	19420
10.	47	39	19842

The pole pieces retain some magnetism even when there is no current flowing through the coils about pole pieces. This residual field was determined by using a coil of a larger area and larger number of turns than the coil used above . Otherwise the process was the same as the process above.

The coil used:
Number of turns in coil = 99.
Mean surface = 5.82 sq. cm.

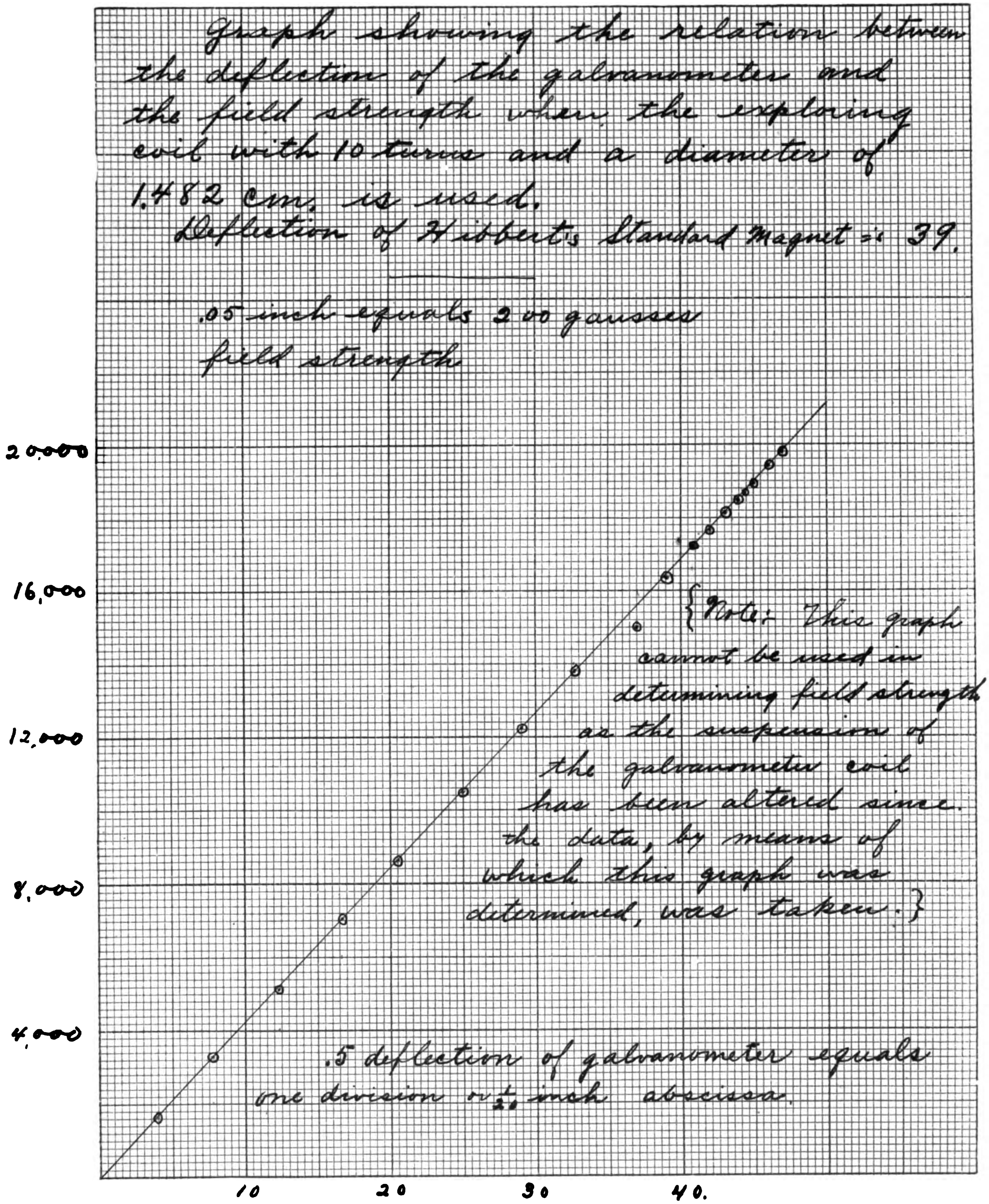
The deflections when using this coil in the circuit were as follows:

Deflection due to exploring coil = 11.
Deflection due to Hibbert's mag. = 36.

By using the equation given on the preceding page,

Residual field = 150.6 gausses.

The following graph shows the relation between deflection and field strength when the coil which has ten turns is used.



Graph showing the relation between the deflection of the galvanometer and the field strength when the exploring coil with 10 turns and a diameter of 1.482 cm. is used.

Deflection of Hibbert's Standard Magnet is 39.

.05 inch equals 200 gausses field strength

{Note:- This graph cannot be used in determining field strength as the suspension of the galvanometer coil has been altered since the data, by means of which this graph was determined, was taken.}

.5 deflection of galvanometer equals one division or $\frac{1}{20}$ inch abscissa.

It will be noticed that the total flux through the Hibbert standard magnet was determined by taking the average of only two results on page 14. In these two results the secondary of the solenoid had 392 turns. The reason that this was done was because this particular secondary was better constructed than the secondary of 600 turns. It fitted over a smaller distance near the middle of the primary and was of such a diameter that it fitted rather closely. The main object in using the secondary of 600 turns was to test the results obtained by the secondary of 392 turns.

As explained on page 17, the graph drawn on that page cannot be used in determining any particular field as the suspension of the coil has been changed since the data was taken from which that graph was determined. The only accurate method for determining the strength is to solve the equation on page 11 .

In using the equation on page 11 the total flux of the Hibbert's standard magnet should be taken at the following value instead of the value given on the standard.

Total Flux of Hibbert's magnet = 31550 lines.

Calibration of an Exploring Coil:

It is often desirable to know the value of the magnetic field strength within a certain limited area, as for instance along an edge, or in a hollow, or at a point. In order to do this a small coil having a small area and a large number of turns was constructed. As neither the number of turns nor the area were known it was necessary to calibrate this coil in a known field. This was done as follows+ Both coils, this small coil and the coil of ten turns used in the preceding experiment, were placed in series on the same circuit and the deflections of each coil when placed in the different field of the electro magnet used in the preceding experiment noted. The exact field strength of the magnet was determined by the coil whose area and number of turns were known. From the equation on page 11 we have

$$H = \frac{N_1 t_1 D_2}{t_2 D_1 A}$$

This equation will hold for this small coil.if we let

t_2 = the number of turns on the small coil,
D_2 = deflection of galvanometer .due to this coil,
and A = the area of this smaller coil.

For any given coil the product of the number of turns and the area is a constant. In the above equation we get the following:-

$$A\ t_2 = \frac{N_1 t_1 D_2}{D_1 H} \qquad (12)$$

Knowing $A \cdot t_2$ for the smaller exploring coil we can use it just as we would a coil whose area and number of turns are known.

Determination of A t_1 for small coil:

Current	D_1	D_2	H	A t_2
1	7.8	4.2	3361	9.2884 *
2	16.	8.7	6894	9.3806
3	24.	13.1	10341	9.4087 *
4	31.5	17.1	13573	9.365
5	37.2	20.1	16030	9.321
6	40.2	21.8	17322	9.355
7	42.2	22.8	18184	9.299
8	43.2	23.8	18614	9.725 *
9	44.1	24.2	19002	9.466 *

The average value of A t_1 = 9.340

In obtaining this average value the values which are starred (*) above were omitted. Astudy of the curve on page 21 will show the reason for omitting these values. The first value was left out in determining the average because the error would probably be large on account of the small deflection of D_2.

In above,

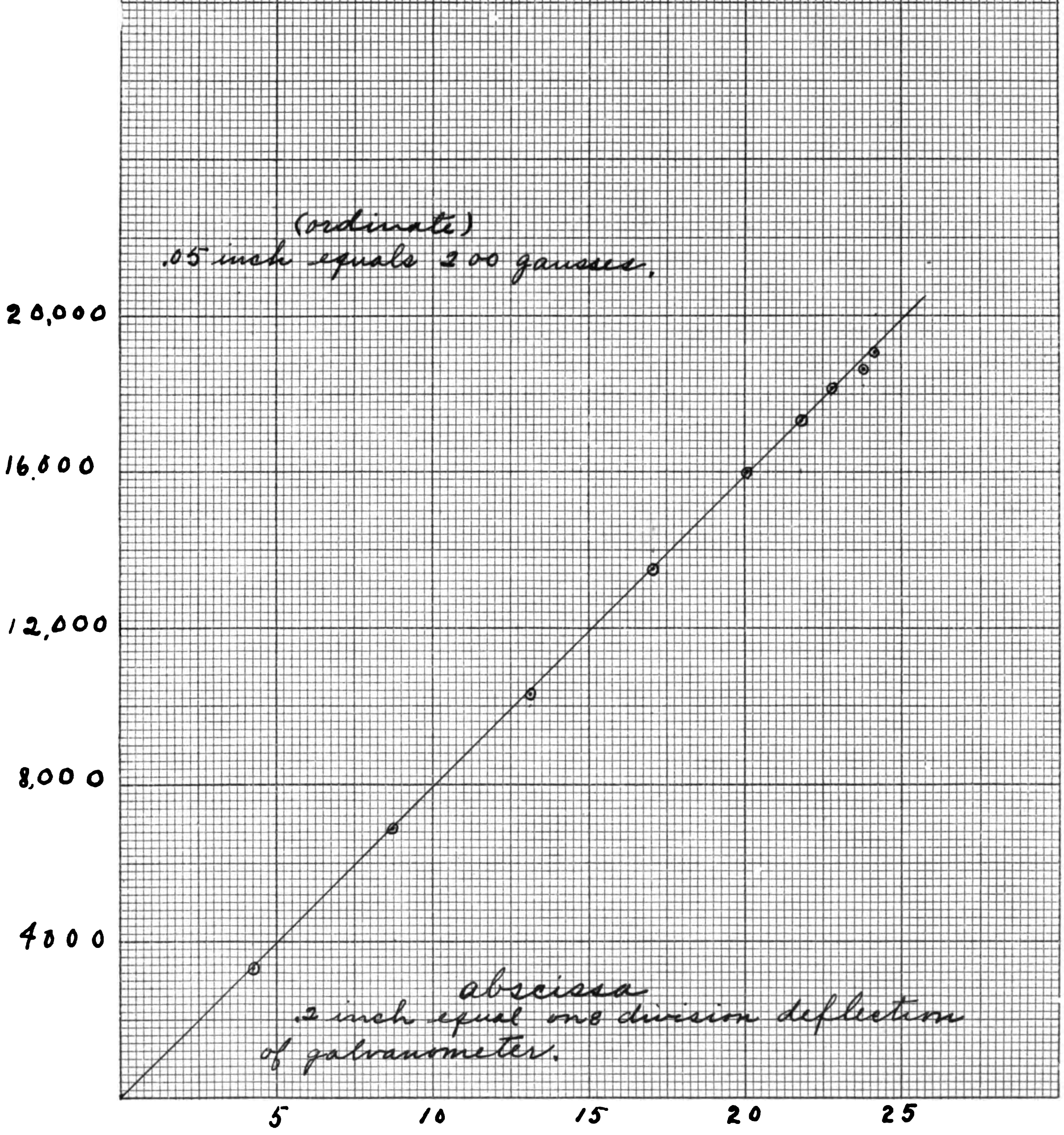
D_1 = deflection due to standard exploring coil.
D_2 = deflection due to small exploring coil.
H = field strengths for different currents.
A t_2 = the product of number of turns and the area of the small exploring coil.
N = total flux through Hibbert's magnet. This is equal to 31550 lines.
t_1 = number of turns of wire on the brass cylinder of Hibbert's magnet and = 9.

In using this coil the following equation with the properly required values will give the field strength.

$$H = \frac{31550}{9.34} \times \frac{9}{1} \times \frac{D_4}{D_1}$$

D_3 = deflection due to the Hibbert's magnet and=s in this case 38.2.

Graph showing the relation between the deflection of the unknown exploring coil and the field strength.



Conclusion:

In operating the apparatus designed and constructed for this thesis a few suggestions may be helpful.

(1) If possible, it lends to the accuracy of the result if the exploring coil can be placed in a fixed position in the field to be measured and the change of flux through the coil gotten by connecting or disconnecting the current through the instrument whose field is to be measured.

(2) Turning the exploring coil through 180 degrees doubles the amount of throw of the galvanometer.

(3) Always standardize the galvanometer for each experiment by means of the Hibbert's magnetic standard.

(4) Remove the Hibbert's standard from the case when using it so as to prevent any unnecessary jarring of the galvanometer.

(5) If the exploring coil is jerked out of the field it should be jerked to a point where the field is negligeable in order to insure a correct deflection of the galvanometer.

(6) Estimate the reading of the galvanometer to one-tenth of one division.

Errors:

As already stated, the largest probable error due to the Hibbert's standard magnet is within two-third of one percent. Assuming that the measurements of the exploring coil and the reading of the deflections of the galvanometer are correct to within one- tenth of one percent and one-tenth of one division respectively, then the total percentage of error of the apparatus, when the deflections are in the neighborhood of forty, (the error there being 1/4%) would be approximately, one percent.

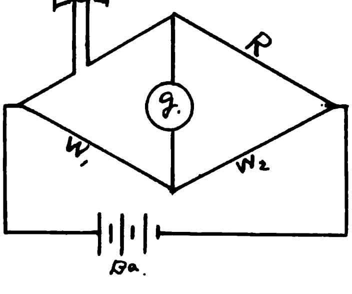
As the percentage of error due to the reading of the deflection would be greater when the deflection is small, it is well to use exploring coils that always give a fairly large deflection.

The Bismuth Spiral:

All metals have the property of changing their resistance when placed in a magnetic field. Bismuth possesses this property to a very marked degree, in fact very much more than other metals. The increase in its resistance is such that in very strong fields and at ordinary room temperatures it is equal to the original resistance. This fact has been made use of in measuring magnetic fields. In the following experiment the pure bismuth wire was wound in the form of a non-inductive spiral between mica plates at the end of a long handle with insulated leads leading down along the handle to the spiral. The spiral was connected by three feet of braided lamp cord per lead to the posts of a Kohlrausch Bridge and the galvanometer used in the preceding experiment was employed to determine the balance of the bridge. As the field of the electro magnet used was already known for different currents the spiral was calibrated in its field.

The Apparatus:

The following diagram shows the arrangement used in making the calibration.



R = ratio coils on bridge.
S = spiral.
w, & w_2 = the parts of the wires on bridge.
E = poles of the electro magnet.
G = galvanometer.

Data:

The bismuth spiral was connected to the Kohlrausch Bridge and placed in the field of the electro magnet. The strength of the field of the magnet for known currents had been determined in the perceding experiments. The following data was determined.

C = the current in the electro magnet.
Br= actual reading on the bridge.
R_s= resistance of the spiral in the various fields.
H = field strength between poles of magnet 5mm. apart for the indicated current.
R_0= resistance of the spiral in zero field.

Temperature = 24 degrees centigrade.

First trial:-

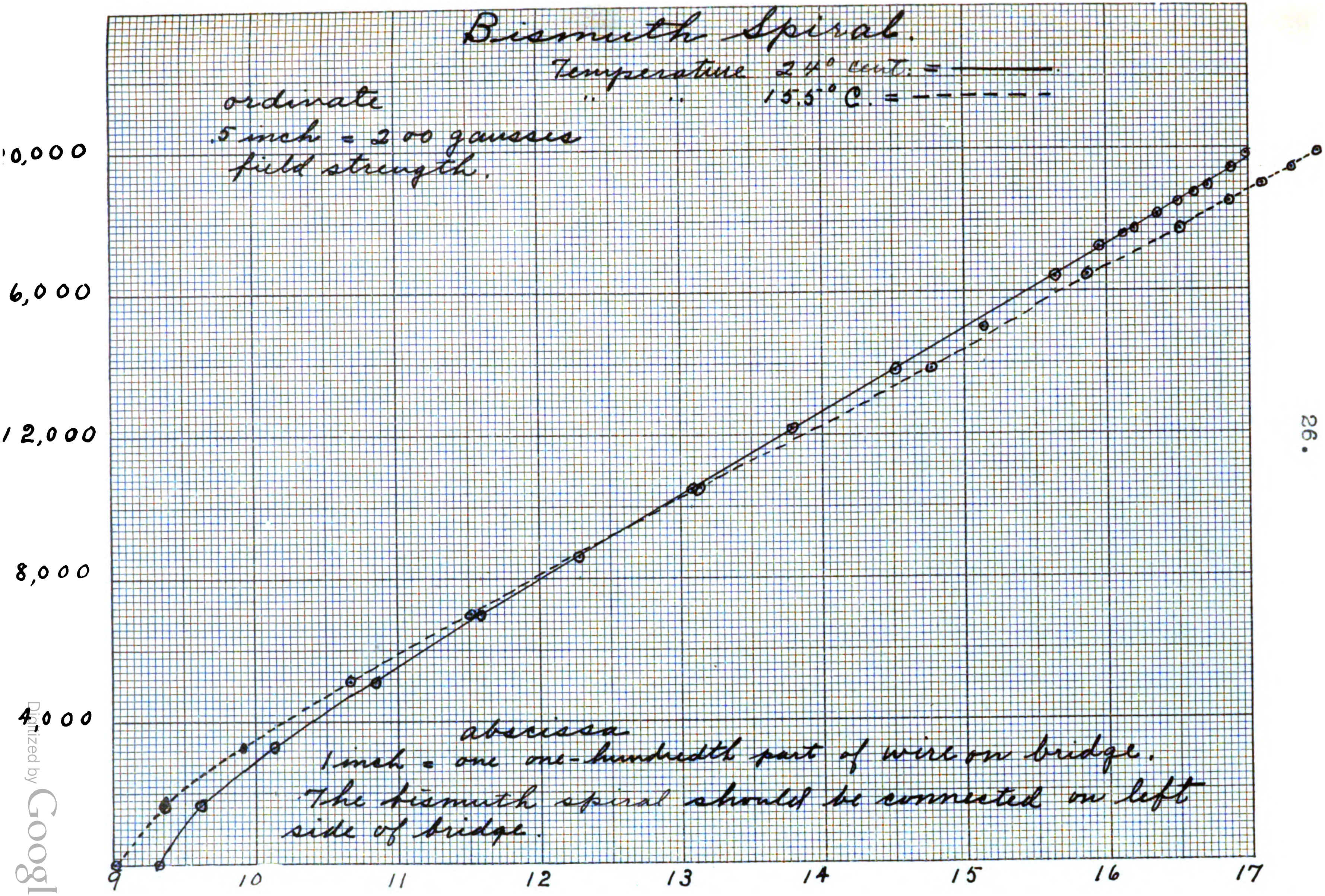
C.	Br.	R_s.	$R_s = R_0$	$\frac{R_s - R_0}{R_0}$	H.
0	9.32	10.28	0	0	00
.5	9.62	10.64	.36	.0350	1688
1.	10.13	11.27	.99	.0963	3293
1.5	10.85	12.17	1.89	.1838	5192
2.	11.58	13.18	2.90	.2821	7018
2.5	12.29	14.01	3.73	.3628	8654
3.	13.08	15.06	4.78	.4653	10553
3.5	13.78	16.02	5.74	.5583	12242
4.	14.52	16.99	6.71	.6527	13802
4.5	15.14	17.84	7.56	.7354	15020
5.	15.63	18.52	8.24	.8015	16464
5.5	15.95	18.98	8.70	.8463	17224
6.	16.20	19.33	9.05	.8803	17730
6.5	16.36	19.56	9.28	.9027	18154
7.	16.5	19.76	9.48	.9222	18490
7.5	16.62	19.93	9.65	.9386	18743
8.	16.71	20.06	9.78	.9514	18997
9.	16.87	20.29	10.01	.9737	19420
10.	16.98	20.45	10.17	.9893	19842

Second Trial:- Temperature = 15.5 degree C.

C.	Br.	R_s	$R_s - R_0$	$\frac{R_s - R_0}{R_0}$	H.
0	9.03	9.93	0		0
.5	9.37	10.34	.41	.0464	1688
1.	9.92	11.01	1.08	.1087	3293
1.5	10.68	11.96	2.03	.2044	5192
2.	11.52	13.02	3.09	.3112	7018
3.	13.11	15.09	5.16	.5196	10553

C.	Br.	R_s	R_s-R_0	$\frac{R_s-R_0}{R_0}$	H
4.	14.78	17.34	7.41	.7462	13802
5.	15.87	18.86	8.93	.8993	16464
6.	16.53	19.80	9.87	.9940	17730
7.	16.87	20.28	10.35	1.042	18490
8.	17.11	20.63	10.70	1.077	18997
9.	17.3	20.92	10.99	1.107	19420
10.	17.44	21.12	11.19	1.126	19842

Two sets of curves have been drawn from the above data. The curves on page 26 show the relation between the field strength and the actual reading of the bridge for the two temperatures in which the data was determined. The curves on page 27 show the relation between $\frac{R_s-R_0}{R_0}$ and the field strength. It is evident that the reading of the spiral is affected by temperature. The curve at the top of page 27 is an attempt to provide a means of determining the temperature of the spiral by making use of the original resistance of the spiral when outside of a magnetic field. Two curves have been drawn between the determined curves to show where the curves would run if the resistance of the spiral in the field were found at 18 and 21 degrees.


Bismuth Spiral.
Temperature 24° cent. = ————
" " 15.5° C. = - - - - - -
ordinate
.5 inch = 200 gausses
field strength.
0,000
6,000
12,000
8,000
4,000
abscissa
1 inch = one one-hundredth part of wire on bridge.
The bismuth spiral should be connected on left side of bridge.
9
10
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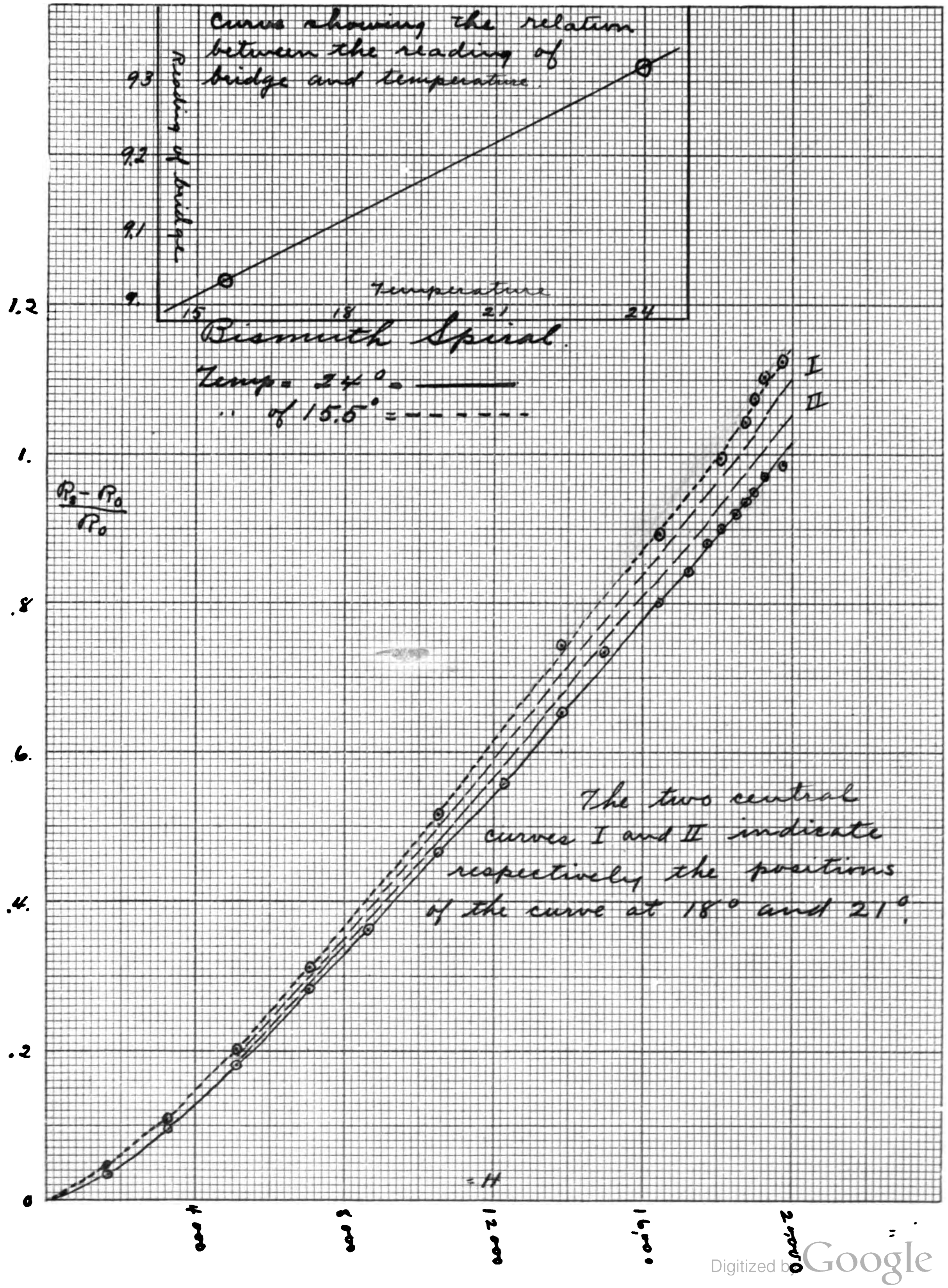

Curve showing the relation between the reading of bridge and temperature

Bismuth Spiral

Temp = 24° = ———

" of 15.5° = - - - - - -

The two central curves I and II indicate respectively the positions of the curve at 18° and 21°.

Approved this 6th day of March 1913

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